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An exploration of think-aloud protocols linked with eye-gaze tracking: are they talking about what they are looking at

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Abstract

This pilot study investigated the use of juxtaposed think aloud and eye-gaze tracking to understand a possible different understanding of think aloud process of participants. Four participants completed eight multiple-choice science questions while thinking aloud and having their eye-gazes tracked. Analysis of the data revealed that participants had behaviors such as fore telling of an eye movement, pauses in the think-aloud, different duration of the think-aloud, and the interaction between the think-aloud and associated eye movements. These findings suggest that juxtaposed think aloud and eye-gaze tracking may be a useful approach to furthering our understanding of students' problem solving behaviors.

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1. Introduction

Think-aloud protocols involve the verbalization of thinking during reading, problem solving, or other cognitive tasks (Baumann, Jones, & Seifert-Kessell, 1993; Davey, 1983; Oster, 2001). Participants might verbalize commentary, questions, generating hypotheses, or drawing conclusions. Thus, think-alouds may serve as both an instructional tool and method of assessment. Significant research has focused on explicit efforts to understand the thinking process and the comprehension of text (Collins, & Smith, 1982; Paris, Cross, & Lipson, 1984; Davey, 1983; Palinscar, & Brown, 1984; Bereiter, & Bird, 1985). Utilizing think-alouds in such a manner involves teacher modeling, teacher-student interaction, and finally, the independent use by the student. However, Beck and Kucan (1997) point out that much of the research does not offer specific examples of this process. Furthermore, those that do offer specific examples, rely heavily on the internalization of the strategy by the student in a later and more independent setting, potentially missing vital information into the process of student thinking.

Limited research has been done with think-alouds and science instruction. Furthermore, the use of think-aloud protocols as a method for assessing inquiry is virtually non-existent. What does exist is limited to strategy presentations demonstrating the use of think-alouds in science lessons. Martin-Hansen and Johnson (2006) present an example of modeling a think-aloud during text reading. However, the authors assert that once this process is modeled, student will independently use this process during science text reading and scientific inquiry. Although

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think-alouds provide scaffolding for students as they engage in higher order thinking (Oster, 2001), a full assessment of their thinking process is limited to what is openly shared in the verbal exchange.

In a different arena of research, eye movements have provided insight into reading and problem solving as well. The use of eye movement data allows researchers to see specific behavioral characteristics associated with these complex cognitive tasks (Reichle, Rayner, & Pollatsek, 2003; Grant, & Spivey, 2003; Knoblich, Ohlsson, & Raney, 2001; Tanenhaus, & Spivey-Knowlton, 1996; Rayner, 1978; Rayner, & McConkie, 1976; Tai, Loehr, & Brigham, 2006). With the emergence of these methodologies and measurements, insight into the core mental operations of language processing and problem solving has grown along with the body of literature supporting the identification of core mental operations.

Eye movement data has been collected in problem solving tasks as well (De Corte, Vershaffel, & Pauwels, 1990; Hegarty & Just, 1993; Hegarty, Mayer, & Green, 1992; Suppes, 1990). Again, the length of fixations as well as the number of fixations increased with the complexity of the problems. Specifically, Hegarty et al. (1992) found that low-accuracy students differed from high-accuracy students during arithmetic word problems. This study provided insight into the mathematical problem solving process and how it is assessed.

It has been argued that eye movement data is not a direct indication of cognitive processing. For example, Anderson, Bothell, and Douglass (2004) argue that eye movements do not reflect retrieval processes are believe that there are weaknesses in the eye-mind relationship. However, Findlay and Walker (1999) provide evidence for the saccadic movement and cognitive processing as parallel actions. The model offered by Rayner (1998) rests on the idea that processing and comprehension greatly influence eye movements. Richardson and Spivey (2004) state that eye movement data lies between perception and cognition and therefore providing insight in to the process of cognition. For example, eye movement data has been used in evaluating reading comprehension (Fletcher, 1993). Yet the most supporting evidence comes from Posner, DiGirolamo, and Fernandez-Duque (1997) in the comparison of neuroimaging methods with eye movement data. Specifically, eye movement data lines up with neuroimaging data for reading, listening, recognizing, and remembering (Posner et. al., 1997). Eye movement research has also been used with processing disorders such as dyslexia (Pavlidis, 1985; De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002), indicating its usefulness in cognitive processing.

Similar to the limitations in using think-alouds with reading comprehension, little research looks at the potential limitations that exist with these protocols and problem solving. This article presents the integration of verbal protocols and eye movement data to provide a more comprehensive look at student thinking. A better understanding of what think-aloud protocols provide and what limitations exist allow for more effective uses of this strategy in both instruction and assessment. The purpose of this study is to integrate a participant's eye movements with their think-aloud data to develop a broader understanding of student thinking and the impact on instruction and assessment.

2. Method

2.1. Participants and setting

This study included four participants, three females and one male, who were students in education at a university in the East coast region. The backgrounds of each participant varied among three main areas: biology, chemistry, and physics. Within each discipline the participants expressed a range of understanding, ability, and confidence with the content. However, for the purposes of this study, understanding, ability, and confidence was largely based upon coursework in a particular area. Each participant was assigned a pseudonym that starts the same first letter as their most comfortable subject, i.e., Betsy is most comfortable with biology where as Chloe is most comfortable with chemistry. All participants possessed normal uncorrected vision ruling out visual acuity as a potential source of variability among the participants. The sample size of this study is limited due to the time necessary for a thorough analysis of both the eye movement and think-aloud data.

2.2. Materials

In this study, participants were asked to complete eight multiple-choice questions containing a think-aloud component. Each item in the assessment was composed of four elements: (a) the text of a question or question stem, (b) an image (a graph, an illustration, or a table/chart), (c) the answer as well as 3 or 4 alternative responses to the question, and (d) a hyperlink to advance to the next question.

This study used standardized science test questions from released items of the Virginia Standards of Learning end-of-course exams in biology and chemistry and the New York State Regents exam in physics. The selected items were converted to HTML format to allow for electronic display.

2.3. Procedure

A demographic survey was given to determine the understanding, ability, and confidence levels for each participant in the given areas of science. The participants were seated in front of the apparatus and positioned to permit data collection. Prior to starting the assessment, the eye tracking system was calibrated. The participants were informed of the overall process and procedure for the study. The test items were presented in the same order to each participant, starting with biology, followed by chemistry and then physics. Although the participants could change their answers within a question, they could not return to a previous question after advancing to the subsequent question.

Each participant was asked to verbalize what he or she was doing in regards to eye movement, thinking process, and problem solving. This process was video taped and transcribed. The transcriptions of the think-aloud were than matched with the eye gaze of participants.

3. Results

The results of this research focused on the juxtaposed eye movement and think-aloud data. Within eye movement data, there were several quantifiable data to report such as time spent in each question, average time spent per participant on eight questions, average time spent per question given (biology, chemistry, and physics), and visual inspections. The think-aloud data were not necessary to analyze on it's own due to the fact that this study's purpose was to explore the combined data of think-aloud with eye movements. Therefore, a thorough inspection of think-aloud and eye movement was conducted for this study.

In this section, a summary of the findings related to juxtaposition of eye movement and think-aloud are presented. First, the findings from qualitative analyses of these juxtaposed graphs are offered using similar themes that arose. Then, selected think-aloud transcriptions from the participants are presented and discussed as examples. The qualitative analyses of juxtaposed graphs had similar themes that we noticed and those are: (a) pause occurred the most in I- and A-zone, (b) longer think-aloud during the first 30 seconds, and (c) longer think-aloud with longer eye gaze in the same zone. These themes are further discussed in the order presented above.

3.1 Pauses in think-aloud

A behavior we observed in this study was the pauses that participants had during their think-aloud process. All four participants had pauses in their think aloud for eight questions they solved, but more importantly, most of the pauses occurred during the I-Zone and A-Zone. This observation may indicate that while problem solving, it may be more difficult to exercise think aloud process. For example, Betsy paused twice while solving the chemistry problem which asked about the effect of a catalyst on the reaction in potential energy curve, both times while looking at the energy curve. Similar to Betsy, Paul paused three times in the I-Zone while solving the same question. The majority of the pauses are observed in the middle to second half of the problem-solving section, which is the period where participants may be immersed in figuring out an answer for the problem.

3.2 Longer think-aloud

Another behavior we observed was that participants had lengthier think-alouds during the first 30 seconds of the problem. Basically, all four participants were able to think-aloud in length while reading the question and observing the image during the first 30 seconds of the question compared to the latter half of problem-solving which caused participants to pause more frequently and give shorter think-alouds. For example, Chloe, while solving Question 1, had one pause in the first 30 seconds of the question whereas she had three pauses in the last 30 seconds of her think-aloud process. On top of more pauses per question in think-aloud, Chloe also gave the lengthiest think-aloud at the 13-second mark with 33 words in total. Other participants had similar patterns of providing lengthier think-alouds in the first 30 seconds of the question and this may be due to the fact that participants are simply taking in the information whereas the second half of the think-aloud requires problem-solving process.

3.3 Longer think-aloud with longer eye gaze

As we assumed before the start of the experiment, participants gave lengthier think-aloud with longer eye gaze, which means that the longer they looked at a certain zone, the longer the think-aloud occurred. The majority of the longer eye gazes and think-alouds occurred in the I-Zone and usually the participants gave on average 20 words or more during these think-alouds. For example, one of the participants, Paul, spent 29 seconds in Question 2 with a total of 41 words in think-aloud; and in Question 3, Paul spent 33 seconds in the I-Zone with lengthier think-aloud of 54 words. Other participants showed similar patterns with longer think-aloud with longer eye-gaze, but mainly in I-Zone and A-Zone, which indicates that images such as graphs, pictures, and charts may take longer to process.

4. Discussion

The purpose of this study was to investigate the use of eye-gaze tracking with think-aloud protocols to develop a better understanding of students thinking while engaging in problem solving. Traditional methods of assessment such as standardized, multiple-choice assessments provide limited information regarding the process utilized to solve the problem. Instead, the only data available is the accuracy of the response or superficial inferences about possible reasons for the selection of an incorrect response. A further assessment seems necessary given the importance of problem-solving aptitude in the sciences. The integration of a think-aloud protocol may provide a more complete insight into problem-solving behaviors, especially when paired with eye movement data. A think-aloud protocol is often utilized to provide insight into processes such as reading and problem solving (Oster, 2001). Although, some research indicates that there are drawbacks to this strategy, particularly in reading. These drawbacks point out that think-alouds may slow down the reading process (Bereiter & Bird, 1985). What is not addressed is the accuracy of think-aloud protocols in providing a complete insight into the reading and problem solving processes. In fact, many researchers identify the usefulness of think-alouds in problem solving (Ericsson & Simon, 1980; Ericsson & Simon, 1993; Pressley & Afflerbach, 1995). The present study presents a different perspective on this method of assessment. Specifically, the incorporation of eye movement data into think-aloud protocols points out a potential concern with this form of assessment.

On the initial examination of the data, it became clear that moments during the think-aloud corresponded with specific eye movements. For example, when Betsy verbalized that she was reading the question; her eyes were fixating within the Question Zone. Again, when Betsy verbalized that she was evaluating options, her eyes were fixate within the Answer Zone. At times of reason and decision making, her eyes moved between the Image Zone and the Answer Zone. These behaviors are both expected and within reasonable expectations (Tai et al., 2006).

Each individual participant possessed a set of characteristics associated with their eye movement behavior. This rather robust collection of characteristics suggests that eye tracking may provide insight into problem solving processes. Specifically, the characteristics associated with areas of self-identified expertise are qualitatively different than areas of self-identified weaknesses, than the movement of participants from novice to expert may be measurable in eye movements. This observation aligns with a relatively new area within Cognitive Science. As individuals become more proficient, i.e., the progression from novice to expert, a level of automaticity in these processes is evident (Bargh, 1994). In automaticity individuals that become highly proficient or experts perform certain tasks without conscious awareness (Bargh & Ferguson, 2000). Bargh (1994) cites one of the "four horsemen" of automaticity is efficiency. This would lend itself to greater periods of silence as an efficient way of processing the problems presented. Given the much smaller scale associated with eye movements, this may very well represent a form of micro-automaticity in problem solving. Quantitative and qualitative differences emerged from the analysis in areas such as the fore telling of an eye movement, pauses in the think-aloud, duration of the think-aloud and the interaction between the think-aloud and associated eye movements.

This evidence suggests that think-aloud protocols may not provide an entire account of the problem solving process. For example, pauses during think-aloud protocols did not always correspond with pauses in eye movements. In fact, in several instances, eye movements continued while the think-aloud paused. These pauses appeared to occur at common areas, the I-Zone and the A-Zone. In addition, the process of fore telling is interesting in that the ability of a student to verbally predict his or her next move prior to eye movement may indicate levels of competence and confidence. Clearly these students are providing valuable information when they do verbalize their actions. What may be missing from this information is flagged by the apparent intake and processing of visual information indicated by the participants' eye movements.

5. Implications

This study provided a glimpse of the possible role of eye movements in assessing student problem solving ability. Further work is needed in this area to investigate the internal processes associated with problem solving. More studies looking at the individual components of this project will provide a clearer picture of behaviors such as fore telling, pauses, and associated eye movements. This study suggests that although think-alouds provide a wealth of information about student thinking during problem solving exercises, it may not provide a complete picture. An implication of this evidence comes in the form of a precaution. Awareness that think-aloud protocols may not provide a complete assessment of student understanding or thinking may better help practitioners use this strategy for cognitive processes such as problem solving. Specifically, the role of the teacher in think-alouds may become as important during times of silence as during verbalizations. To avoid throwing the baby out with the bath water, the implications of this study should encourage the use of multiple approaches to assessment and not discourage the use of think-alouds. Furthermore, eye movement behaviors and think-aloud protocols as a means for detecting the development of a micro-automaticity may provide the first glimpse at the progression of an individual from the novice stage through the expert stage into the automation of certain cognitive processes. With the limited forms of standardized assessment for problem solving, educators will benefit from a multifaceted approach to this cognitive process.

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